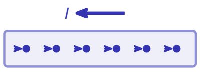
Electricity

AS Physics ▪ Topic 9

A-Level Physics



What we will cover

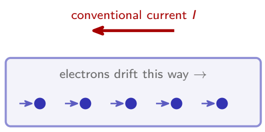
1 Current and charge

Electric current

Current 电流 is a flow of **charge carriers** 载流子.

- metal: conduction **electrons** 电子
- electrolyte: positive & negative **ions** 离子

> Conventional current flows the way positive charge would – opposite to the electrons in a wire.



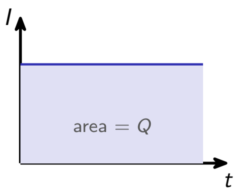
Charge and current

Charge is **quantised** 量子化: every free charge is a whole-number multiple of the **elementary charge** 基本电荷 $e = 1.60 \times 10^{-19}\,\mathrm{C}$, measured in **coulombs** 库仑. **Current** 电流 is the rate of flow of charge past a point:

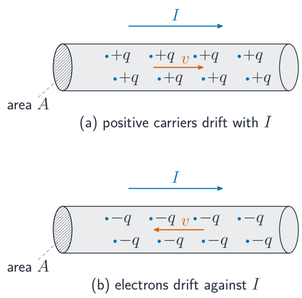
$$I = \frac{Q}{t}, \qquad Q = It.$$

$0.50\,\mathrm{A}$ for 2.0 min

$Q = 0.50 \times 120 = 60\,\mathrm{C}$,
$N = Q/e \approx 3.8 \times 10^{20}$ electrons



Drift velocity



$$I = A\,n\,v\,q$$

A is the **cross-sectional area** 横截面积, n the **number density** 数密度 of carriers, q their charge and v the **drift velocity** 漂移速度.

> A thinner wire at the same I needs a faster drift. In **series** 串联, I is the same everywhere, so nv must change to compensate.

Copper, $A = 10^{-6}\,\mathrm{m^2}$, $I = 5.0\,\mathrm{A}$

$v \approx 3.7 \times 10^{-4}\,\mathrm{m\,s^{-1}}$ – under 1 mm per second

2 Potential difference and power

Potential difference and e.m.f.

Voltage 电压 is energy transferred per unit charge, measured in **volts** 伏特:

$$V = \frac{W}{Q}, \qquad [V] = \mathrm{V} = \mathrm{J\,C^{-1}}.$$

e.m.f. 电动势

energy given to the charge by the source

p.d.

energy given up to a component

Electrical power

$$P = VI = I^2R = \frac{V^2}{R}.$$

Pick the form for the quantities you know.

Kettle "$2.4\,\mathrm{kW}$, $240\,\mathrm{V}$"

$I = P/V = 10\,\mathrm{A}$, $R = V^2/P = 24\,\Omega$

$P = VI$

substitute $V = IR$ → $P = I^2R$

substitute $I = \frac{V}{R}$ → $P = \frac{V^2}{R}$

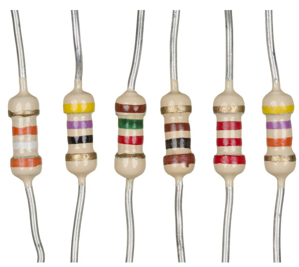
3 Resistance and Ohm's law

Resistance and Ohm's law

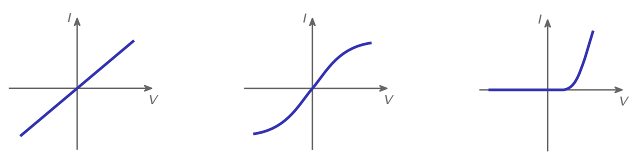
$$R = \frac{V}{I}, \qquad [R] = \Omega = \mathrm{V\,A^{-1}}.$$

> Ohm's law: $I \propto V$ *at constant temperature* – then R is constant (a straight I–V line).

$R = V/I$ defines R for *any* component; only ohmic ones keep it constant. A metal's resistivity rises with temperature – more **lattice vibration** 晶格振动 **scatters** 散射 the electrons. An **insulator** 绝缘体 sits near $10^{15}\,\Omega\,\mathrm{m}$.



I–V characteristics

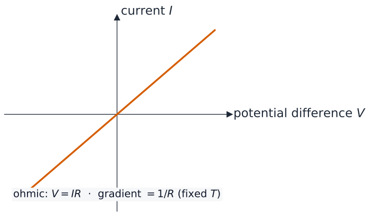


metal: straight *lamp: R rises* *diode: switch-on*

A hotter **filament lamp** 灯丝灯泡 has more resistance; a **diode** 二极管 conducts only above $\sim 0.7\,\mathrm{V}$.

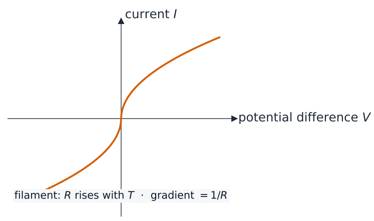
Characteristic 1 – a metal wire

Straight through the origin: R is constant, so the wire obeys Ohm's law (provided its temperature does not change).



Characteristic 2 – a filament lamp

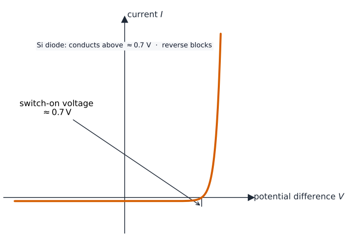
The curve bends over: as the current heats the filament its resistance rises, so equal steps in V buy less and less current.



Characteristic 3 – a diode

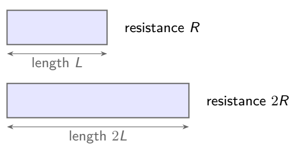
A **semiconductor diode** 半导体二极管 conducts one way only, and only above about $0.6\,\mathrm{V}$.

In reverse the current is negligible until breakdown – which is why a diode can turn a.c. into d.c.



Resistivity

same area A – twice the length gives twice R



$R \propto L$

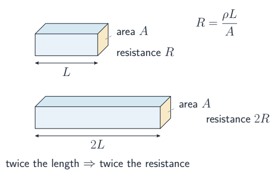
$$R = \frac{\rho L}{A}.$$

ρ is the **resistivity** 电阻率 (a material property, $\Omega\,\mathrm{m}$).

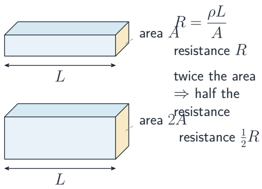
Copper: $L = 2.0\,\mathrm{m}$, $A = 1.7 \times 10^{-7}\,\mathrm{m}^2$

$$R = \frac{(1.7 \times 10^{-8})(2.0)}{1.7 \times 10^{-7}} = 0.20\,\Omega$$

What $R = \rho L/A$ is saying



Twice the length, twice the resistance.

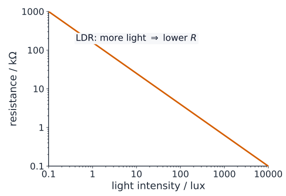


Twice the area, half the resistance.

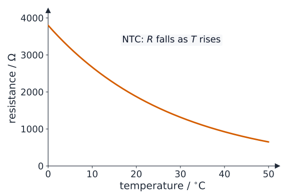
ρ is the **resistivity** 电阻率, a property of the material alone, in $\Omega\,\mathrm{m}$; R also depends on the shape.

4 Sensors

Light-dependent resistor and thermistor



LDR 光敏电阻: *R falls as light rises*



thermistor 热敏电阻: *R falls as temp. rises*

> Both are semiconductors: light or heat frees more carriers, so R falls – the opposite of a metal.

Two words the definitions turn on

E.m.f.	The **electromotive force** 电动势 (e.m.f.) of a source is the energy given per unit charge by the source; potential difference is the energy *delivered* per unit charge to a component.
Potential divider	Put a thermistor or LDR in a **potential divider** 分压器 and the output voltage changes with temperature or light – the standard sensing circuit.
In parallel	Two resistors in **parallel** 并联 across the same **voltage** 电压: the *smaller* resistance takes more power, since $P = V^2/R$.

> E.m.f. and p.d. share a unit and a symbol but not a meaning. Say "per unit charge" in both definitions, and name which way the energy goes.

Exam tips

- Use $I = Q/t$, $V = W/Q$ (energy per unit charge) and $P = VI = I^2R = V^2/R$.
- **Ohm's law** ($V = IR$) applies only to an ohmic conductor at constant temperature – a filament lamp is non-ohmic.
- Sketch and interpret the I–V **characteristics** of a resistor, filament lamp and diode.
- An **LDR's** resistance falls with light; a **thermistor's** falls as temperature rises.

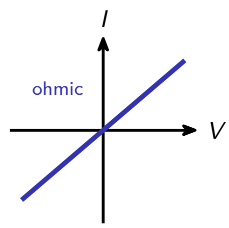
5 Recap

Topic 9 – key takeaways

1. **Current**
   $I = Q/t = Anvq$; conventional = positive flow
2. **Power**
   $P = VI = I^2R = V^2/R$
3. **Resistance**
   $R = V/I = \rho L/A$; Ohm's law if T constant
4. **Sensors**
   LDR and thermistor: R falls with light / heat

Check yourself

1. Charge passing in 10 s at 2.0 A?
2. Three forms of the power equation?
3. Why does a filament lamp's I–V line curve?
4. What happens to an LDR's R in the dark?



> **Answers** **1.** $Q = It = 20\,\mathrm{C}$ **2.** VI, I^2R, V^2/R **3.** R rises as it heats **4.** rises (to MΩ)